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# SPECIFIC ENERGY ABSORPTION CAPACITY OF GLASS-POLYESTER COMPOSITE TUBES UNDER STATIC COMPRESSIVE LOADING

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The experimental determination of energy of glass-polyester composite tubes static fracture is done. The tubes are of defined structure and known processes of fabrication. The aim was to determine the possibility of their usage as damping elements during impact. Two types of tubular samples with different diameters were tested until fracture under static (low speed) compressive loading. The applied forces and sample lengths were measured until complete destruction of samples. From the diagrams received directly from testing devices, certain energy values explained in the paper were determined.

*Key words:* Polymer-matrix composites, Specific energy absorption; Low velocity compression

**Specifična absobcijska energija staklo-poliester kompozitne cijevi pod statičkim tlačnim opterećenjem.** U radu je prikazano eksperimentalno određivanje statičke energije loma staklo-poliester kompozitnih cijevi poznate struktura materijala i postupka izrade. Cilj ispitivanja je bio odrediti mogućnost primjene ugradnje takvih cijevi u elemente za prigušivače udara. Pod djelovanjem spornog statičkog tlačnog opterećenja ispitivana su dva tipa cijevi različitih presjeka. Pri tom su mjerene primenjene sile i duljine uzoraka sve do potpunog loma cijevi. Na osnovu dobivenih dijagrama su izračunate vrijednosti specifičnih energija apsorpcije.

*Ključne riječi:* polimer matrični kompoziti, specifična energija apsorpcije, sabijanje malom brzinom

## INTRODUCTION

Composite materials are often used to reduce the weight of structures. In the automotive industry weight reduction is important because fuel consumption is directly related to vehicular weight. There is an increased concern for occupant safety during roadway accidents. Metals are currently used in car frames and integrated frame-body structures, and these and other metallic components are designed to passively absorb energy during accidents. However, automotive manufacturers are moving toward nontraditional materials [1] and new structural material under consideration should be capable of participating in the energy absorption process associated with accidents. An important parameter when studying energy absorption, and one often used in the automotive industry, is the energy absorbed per unit mass of crushed material. This is often called the *specific energy absorption* (SEA) [2]. The SEA provides a measure of energy absorption efficiency of a structural component but, of course, says nothing about the efficiency of the structure in regards to other areas, such as resisting buckling, damping vibrations, or its ease of manufacture. It is one of several parameters that must be considered in automotive design.

The subject of the paper [3] was investigation of the effect of interlaminar fracture toughness on the specific energy absorption of stitched glass/polyester composite cylindrical shells under axial compression. The laminated composite cylindrical shells, used as energy absorbers, absorb large amount of impact energy during collision. Since delamination in the thin wall of axially collapsed shell is one of the major energy absorbing modes, contribution to SEA of tubes is significant during collision.

The energy absorbing capability of fiber reinforcement polymer (FRP) composite cylindrical tubes used as energy absorbers, by destroying itself progressively, depends on the way in which tube material is crushed i.e., trend of petalling [4]. This paper investigates the influence of fibre orientation and stacking sequence on the petal formation and specific energy absorption (SEA) of glass/polyester composite cylindrical shells under axial compression. Processing conditions effect on specific energy absorption capacity of composite tubes was investigated in [5].

Tubes of circular and square cross sections were fabricated using orthophthalic polyester resin and plain weave E-glass fabric with fibers oriented at 0° / 90°, with respect to the tube axis. Test specimens consisting of tube segments were prepared and tested under static compression load.

Very important factor in the study of energy absorption for energy management capabilities is the shape of

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the crush load vs. crush length graph. As the crushing begins, the load quickly rises to a peak value, then drops off slightly and stays relatively constant. In this way the energy absorption is maximized for the length of crushed material. One does not want the initial peak load ($F_{imax}$) to be much greater than the average crush load ($F_a$), because large loads would be needed to initiate crushing, and the goal in energy management is to absorb all the energy without imparting large forces to the people involved. One measure that is used to characterize the shape of the graph is called the *load ratio* [2]. The load ratio, which is defined as:

$$Load\,ratio = \frac{F_{i\max}}{F_a} \tag{1}$$

is one metric that may be used as an important parameter for measuring crushing efficiency.

## EXPERIMENTAL WORK

The pipes of producer “Poliester” from Priboj were tested. The properties were given in official certificates of certain producers of components made of used glass-polyester pipes. The producers of reinforced glass fibers A.D. “OHIS” and “Vidoe Smilevski-Bato” from Gostivar-Macedonia by certificate confirm “E” glass with 1 % of alkali. Thermo-reactive polyester resin was used as matrix, produced by “Color”-Medvode from Slovenia. Certificate was given for “COLPOLY 7510” for the type: UP/SOM which is highly reactive, low with viscose polyester with the basis of ortoftaly acid in standard glycol.

The pipes were made by the method “Filament Winding”, with structure $[90°]_2[\pm 55°]_4[90°]_4$. Two samples of pipe were made, with outside diameter ∅ 70 mm and ∅ 50 mm.

The specimens for specific energy absorption (SEA) tests (three specimens per each test) were cut from the samples of pipes (Tables 1 and 2). The cut was done on machine type NC-2010 (Nr 95110, Ar 001) with diamond tip tools and at speeds which minimized heating of samples.

Testing (SEA) was done on servo-hydraulic testing machine INSTRON 1332 with controller INSTRON FAST TRACK 80800, with the usage of hydraulic jaws. The testing was defined by standard ASTM D 3039 [6, 7]. Loading was measured with a load cell of 100 kN capacity. Displacements were measured by double extensometer HOTTINGER DD1. The static specimen was placed on the stationary lower plate with the beveled end up. The cross-head was then lowered until the upper plate was just touching the specimen. The cross-head was then set into motion and the load and cross-head displacement were recorded for each test.

## RESULTS AND DISCUSSION

During the test the diagrams crush load – crush length (*F*-*s*) were plot, Figures 1 and 2.

Table 1 **The dimensions of tested samples**

| Specimen | Outside diameter / mm | Inside diameter / mm | Thickness / mm |
|---|---|---|---|
| T-70-1 | 70,9 | 63,8 | 3,6 |
| T-70-2 | 71,1 | 63,9 | 3,6 |
| T-70-3 | 70,6 | 63,9 | 3,4 |
| T-50-1 | 50,5 | 36,4 | 3,4 |
| T-50-2 | 50,3 | 36,1 | 3,6 |
| T-50-3 | 49,9 | 36,3 | 3,4 |

Table 2 **The dimensions of tested samples**

| Specimen | Length of the specimen / mm | Volume / mm$^3$ | Load speed / mm/min |
|---|---|---|---|
| T-70-1 | 128,3 | 4823,7 | 5 |
| T-70-2 | 126,9 | 5166,7 | |
| T-70-3 | 132,1 | 4657,4 | |
| T-50-1 | 129,1 | 3215,9 | 1 |
| T-50-2 | 131,2 | 3540,2 | |
| T-50-3 | 127,3 | 3157,4 | |

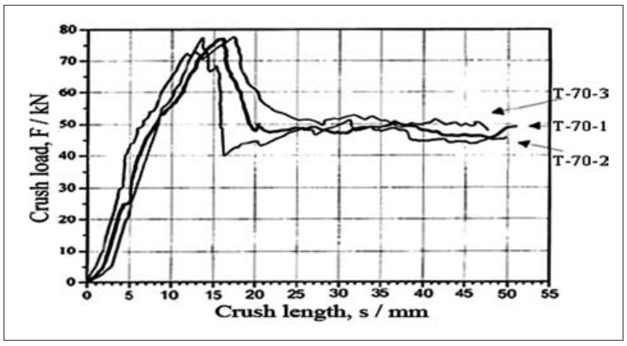

**Figure 1** Crush load vs., crush length for static test (specimen 70 mm diameter (T-70))

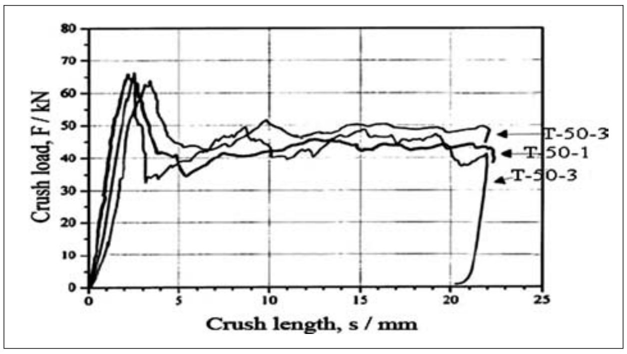

**Figure 2** Crush load vs., crush length for static test (specimen 50 mm diameter (T-50))

The most important parameter that was from each crush test was the specific energy absorption (SEA). Energy is the product of the force and distance moved at the force level. The energy absorbed during crush, E, was calculated by integrating under the crush load vs. crush distance curve,

$$E = \int_0^{s_f} F \cdot ds \tag{2}$$

Where $s_f$ is the final crush length.

The average crush force was calculated continuously as the tube was crushed, as follows:

$$F_a = \frac{\int_0^s F \cdot ds}{s} \tag{3}$$

In order to calculate the load ratio using Equation (1), the value of the crush load at the initial peak, $F_{imax}$, was divided by the average crush load,

$$Load\,ratio = \frac{F_{i\max}}{F_a} = \frac{F_{i\max} \cdot s}{\int_0^s F \cdot ds} \tag{4}$$

To get the SEA, the energy absorbed during crush was divided by the mass of the crushed material, $m_c$. The crushed mass was found by the following:

$$m_c = m_l \cdot s_f \tag{5}$$

Where $m_l$ is the linear density or mass per unit length of the tube, (average value was 1250 g). The linear density was determined from the length and mass measurements from each specimen. Specific energy absorption is defined as:

$$SEA = \frac{E}{m_c} = \frac{\int_0^{s_f} Fds}{m_l \cdot s_f} \tag{6}$$

The experimental results are presented in Tables 3 and 4.

From Figures 1 and 2 we obtained values of energy absorption during crash, crush length, and initial peek of load. Load radio was calculated from Equation 4 and specific energy absorption from Equation 6. Mass of the crushed material was obtained from Equation 5.

The valley-to-peak variations seen in the crush load vs. crush distance graphs varied. Overall, the T-70 specimens showed smaller valley-to-peak variations in the crushing load than did the T-50 specimens.

Average value of energy absorbed during crush was 946,2 J for the samples T-70 and 450,7 J for the samples T-50. Average specific energy absorption (SEA) was 40,1 J/g for the samples T-70 and 37,2 J/g for the samples T-50 and average load ratio 1,25, for the T-70 samples, and 1,28 for the T-50 samples.

Several different modes of fracture can be seen in Figure 3, taken from Sample T-70. The tube wall was torn, while the inner side wall was buckling to the interior of the tubes, and the external side was buckling to the outside.

Between these two areas remained crumbled material that is likely to help the wall separate. Buckling was due to the stress increase in the undamaged part of the tube. After exceeding allowed stress, at the same time, cracks appeared in several places along the tube length, accompanied by acoustic effects. During the fragmentation small number of fibers along the tube were damaged, but there has been more significant damage in material matrix. Tear away parts of the wall that were in the forms of leaves remained undamaged.

Table 3 **Test results**

| Specimen | Initial peek load / kN | Average crush load / kN | Crush length / mm | Load ratio $F_{i\,max}/F_a$ |
|---|---|---|---|---|
| T-70-1 | 78 | 61 | 52 | 1,27 |
| T-70-2 | 78 | 63 | 50 | 1,23 |
| T-70-3 | 78 | 62 | 47 | 1,26 |
| T-50-1 | 66 | 52 | 22,2 | 1,27 |
| T-50-2 | 67 | 51 | 21,8 | 1,31 |
| T-50-3 | 63 | 50 | 22,0 | 1,26 |

Table 4 **Test results**

| Specimen | Energy absorbed during crush / J | Mass of the crushed material / g | Specific energy absorption / J/g |
|---|---|---|---|
| T-70-1 | 958,3 | 24 | 39,9 |
| T-70-2 | 940,6 | 25 | 37,6 |
| T-70-3 | 939,8 | 22 | 42,7 |
| T-50-1 | 462,8 | 12,0 | 38,5 |
| T-50-2 | 447,1 | 12,5 | 35,8 |
| T-50-3 | 442,3 | 11,9 | 37,2 |

**Figure 3** Crush mode

Micromechanical analysis of failure can show that the compression load crack is initiated in all test specimens on the side of outer layer (Figure 4).

Occurrence of the break was at the moment of reaching critical state of stress in the material which causes the occurrence of critical value of crack and its progressive growth. The place of critical crack is related to fiber-matrix debonding (Figure 5) after which the fibers cracked. It is obvious that on the spot where the first break appeared (outer layer) exist more broken fibers which were previously debonded and pulled out from the matrix. Crack propagation leads through to the inner surface of test specimen in transversal direction of test specimen.

Lateral on this crack, in test specimens appeared cracks and delamination (Figure 6) as result of shear stresses in the layers. Existence of shear stresses is characteristic for impact and specially compression test were inner layers were exposed to great axial stresses.

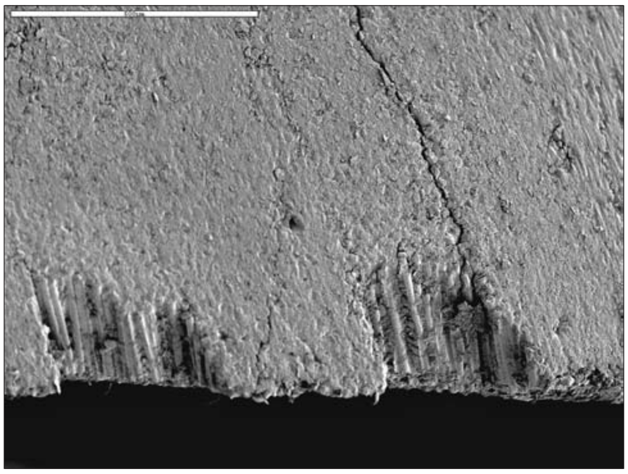

**Figure 4** Compression load crack initiated on the side of outer layer

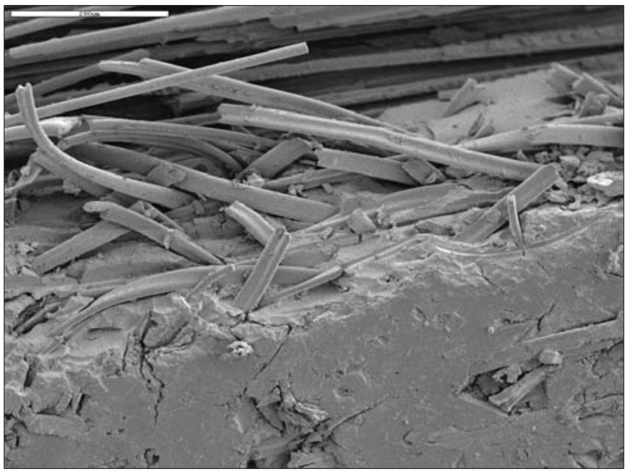

**Figure 5** Fiber-matrix debonding

## CONCLUSIONS

The aim of presented paper was to investigate the possibilities of application of glass polyester composite tubes as elements for depreciation or absorption of energy. The objective was to compare how the energy absorption characteristics were changed by varying circular cross-section area.

On the basis of the result obtained, it can be noted that as regards the energy absorbed during static loads it is better to use larger diameter pipes. Also, as mentioned in [2], a load ratio of less than 1,25 is desirable, which is the case in the sample T-70, that confirms the previous statement. Of course, the validity of these quantities must be questioned because of the large valley-to-peak variations and the non-distinct initial peaks. The high tow count material has proven that it can be effective in energy absorption, so further study is warranted.

The authors of this work plan to continue researches in this field to complete the knowledge about the real possibilities of absorption of energy of structures like this. There are many interesting avenues to explore as a continuation of this work. First of all it is important to investigate dynamic impact crushing because the specimens tested statically tended to absorb more energy than those tested dynamically. Also dynamic specimens generally have higher load rations and crush modes are different. Also, further researches will go in direction of additional standard impact tests by Sharpy method on specimens cut out of tubes. That will give us knowledge about impact toughness of tested structures, but also we will have knowledge about much more important datum, and that is, what is the energy of crack initiation, and what is the energy of crack propagation. By comparison of these values with shown results of energy on static compressive loading we will compare and confirm which energy is more dominant for case of amortization and later, come to conclusions give recommendations about the change of structure to improve these properties. Certainly, as a very useful daum we will get the strength got by standard testing on static pressure loading on test tubes cut out of tubes. In the end, we plan the research in other direction, and that would be finding optimal diameter and length of tubes. We will do all done and planned new tests with longer diameters and shorter lengths.

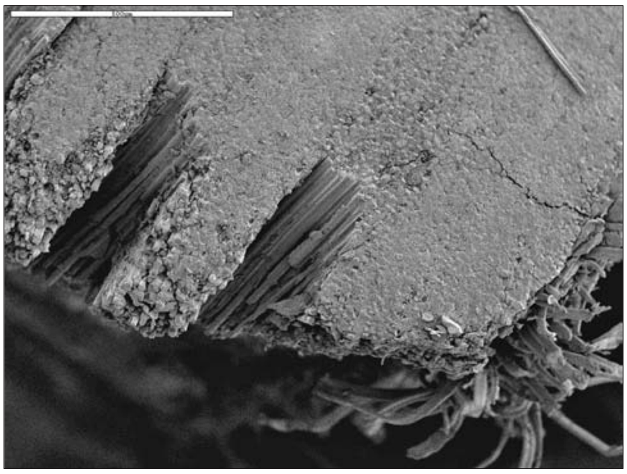

**Figure 6** Cracks and delamination

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**Note:** The responsible person for English language is lecture from Belgrade Polytechnik, Serbia.